Ocean Engineering 84 (2014) 176–182

Contents lists available at ScienceDirect

Ocean Engineering

journal homepage: www.elsevier.com/locate/oceaneng

Scour protection of submarine pipelines using rubber plates underneath the pipes

Lipeng Yang [a,b], Bing Shi [a], Yakun Guo [b,*], Lixiang Zhang [c], Jisheng Zhang [d,e], Yan Han [a]

[a] College of Engineering, Ocean University of China, Qingdao 266100, China
[b] School of Engineering, University of Aberdeen, Aberdeen AB24 3UE, UK
[c] Department of Engineering Mechanics, Kunming University of Science and Technology, Kunming 650031, China
[d] State Key Laboratory of Hydrology-Water Resources and Hydraulic Engineering, Hohai University, Nanjing 210098, China
[e] College of Harbour, Coastal and Offshore Engineering, Hohai University, Nanjing 210098, China

ARTICLE INFO

Article history:
Received 28 June 2013
Accepted 5 April 2014
Available online 4 May 2014

Keywords:
Submarine pipeline
Unidirectional flow
Rubber plate
Critical pressure difference
Critical length of plate

ABSTRACT

This paper presents the results from laboratory experiments to investigate the protection of scour around submarine pipelines under unidirectional flow using a rubber plate placed underneath the pipes. The pressure difference on the two sides of the pipeline is the driving force to initiate the movement of sediment particles and can be obtained by force balance analysis. Experiments covering a wide range of incoming flow velocity, pipe diameter and plate length show that there exists a critical pressure difference over which the movement of sediment and, thus, scour takes place. Analysis of the experimental results demonstrates that this critical pressure difference is related to the pressure difference of the axial points between upstream and downstream of the pipe, which can be easily determined. This critical pressure difference is used to develop an empirical formula for estimating the critical length of the rubber plate, over which the sediment movement and scour will not take place. Good agreement between the experiments and calculated critical plate length using the proposed formula is obtained.

1. Introduction

Submarine pipelines have been extensively studied in past decades due to its practical important application in offshore engineering. The stability and survivability of the submarine pipelines is among one of the focused studies. Many uncertain factors can cause the instability of the submarine pipelines. As such, the accidents of the failure and damage of the submarine pipelines have often occurred (Morelissen et al., 2003). One of the important factors causing such accidents is that the pipeline is suspended due to the local scour of the seabed underneath the pipe. Such local seabed scour can be greatly enhanced due to the presence of the submarine pipelines, which change the local flow pattern and increase the sediment transport capacity (Sumer et al., 2001a). Many studies have been carried out to investigate the mechanism of local scour (see, for example, Mao, 1986; Chiew, 1990, 1992; Sumer and Fredsøe, 1990, 2001; Sudhan et al., 2002; and the excellent review paper and book by Sumer et al., 2001b; Sumer and Fredsøe, 2002) and the protection method of the pipeline. One of the protection approaches is to artificially bury the pipeline. However, this method will significantly increase the cost. For the pipeline laid on natural seabed, it can bury itself (the so-called self-burial; Sumer et al., 2001a) under certain marine conditions as a result of the local seabed scour. Previous studies showed that such self-burial process and extent of scouring can be greatly accelerated by attaching a solid spoiler at the top of the pipe (Hulsbergen, 1984, 1986; Gokce and Gunbak, 1991; Chiew, 1992; Bijker, 2000; Cheng and Chew, 2003; Li and Cheng, 1999; Cheng et al., 2009; Yang et al., 2012a, 2012b). However, the attachment of a solid spoiler also increases the disturbance intensity of the flow which in turn causes the vibration of the pipe and induces the scour downstream. In addition, successful self-burial of a pipe with or without a spoiler does require certain seabed conditions. For example, if the seabed consists of substantial clay or gravel, the self-burial of the pipeline, even with a spoiler, may not take place. Furthermore, the extent of self-burial which depends on the complex interaction of flow–soil–structure (pipelines and spoiler) could be an another issue. The alternative approach for protecting the submarine pipelines is to reduce or/and prevent the scour around the pipes. Chiew (1990) investigated the prevention of the onset of the scour by placing an impermeable plate on the upstream side of the pipeline. This paper demonstrates the protection of scour around the submarine pipelines by placing a rubber plate underneath the pipe. The study shows that the presence of the rubber plate can greatly influence the scour around the pipeline. The laboratory experiments reveal that the scour depth depends on the length of the rubber plate

* Corresponding author. Tel.: +44 1224 272936.
E-mail address: y.guo@abdn.ac.uk (Y. Guo).

http://dx.doi.org/10.1016/j.oceaneng.2014.04.006
0029-8018/

Nomenclature

C_L	the coefficient of uplift force, which is 0.178 (Chien and Wan, 1999)
D	diameter of the pipe
d	mean diameter of sediment
g	gravitational acceleration
h_f	scour depth with a rubber plate
h_0	scour depth without a plate
k	correction coefficient
L	length of plate
m	coefficient related to flow Reynolds number
p_1	reference pressure at undisturbed upstream
R_0	radius of the pipe
S	specific gravity of sediment particles
u_b	bottom velocity of water on the seabed
X	horizontal distance on the bed which is symmetrical to the axis of the pipe
y	distance along the pipe surface from point B'
α	angle defined in Fig. 3 with the value of 0.22 rad in this study
λ	calibration coefficient
λ_A	calibration coefficient
ρ	specific weight of water
ρ_s	specific weight of sediment particles
μ	correction coefficient

for otherwise identical experimental conditions. A critical plate length exists over which the scour around the pipes does not take place. Such critical plate length depends on the pipe diameter, sand/soil and flow conditions, which are investigated in this study.

2. Experimental set up and procedure

The laboratory experiments were carried out in a horizontal wave and current loop which is 24.8 m long, 0.5 m wide and 0.6 m deep. The tested pipes with a length of 0.5 m were installed at two locations of the loop and they were 5.0 m away from the flume beds (see Fig. 1). Sandy bed of 0.15 m high and 6 m long was arranged on one side of the flume and a fixed bed of the same level was on the other side. The scour profiles around the pipeline and the final scour depth were measured using a depth probe. Sixteen pressure probes were symmetrically installed around the pipe axis at the surface of the fixed bed, which were 2.7, 4.5, 6.3, 9.0, 12.2, 17.0, 22.0 and 32.5 cm away from the pipe axis. The measured pressure distribution on the surface was used to calculate the pressure difference between two symmetrical points with respect to the pipe axis. Various lengths of the rubber plates with the thickness of 1 mm are placed under the pipe on both the sandy and fixed beds (see Fig. 2). The plates are placed above the pressure sensors on the fixed bed.

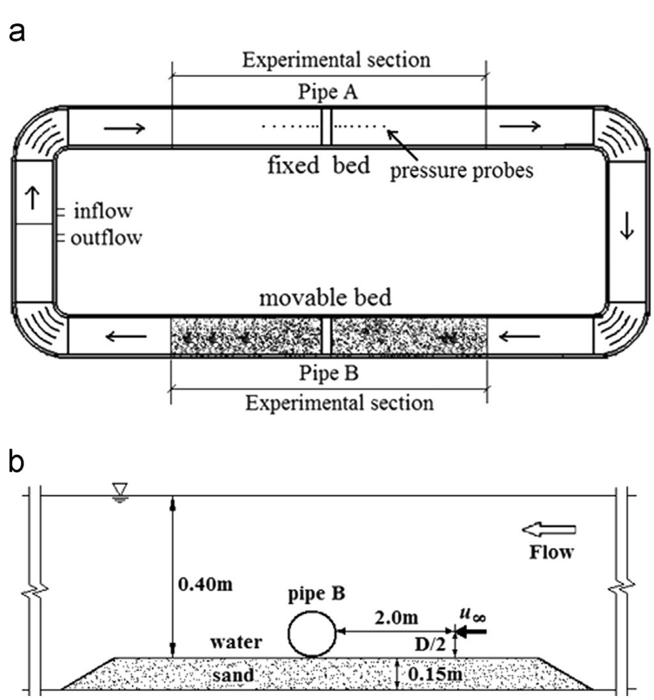

Fig. 1. The flume experimental arrangement: (a) the plane view and (b) the side view.

The pipe investigated here has an outer diameter (D) of 0.05 m, 0.07 m, 0.09 m, 0.10 m, 0.11 m and 0.13 m. Several plate lengths (L=0.7–2.3D) were used in experiments. The plate is impermeable and fixed to the bottom of the pipe. The water temperature was measured using a thermometer and kept as constant of 16 °C (the corresponding kinematic viscosity $\nu=1.118\times10^{-6}$ m^2/s). Water depth is kept as constant of 0.4 m for the majority of the experiments. The velocities at the different heights from the bed were measured using an Acoustic Doppler Velocimeter (ADV). The velocity measured at 0.5D from the bed and 2 m away from the pipe (as shown in Fig. 1(b)) is used as the inflow velocity (u_∞), varying from 0.24 m/s to 0.50 m/s. The mean diameter of sediment used in all experiments is d=0.56 mm and the porosity of the sediment is kept as n=0.4. The experimental parameters are listed in Table 1 in which experiments in group A are used to determine the parameters in Eq. (7), while experiments in groups B and C are used to verify the derived formula for estimating the critical length of the plate. The mechanical properties of rubber plate investigated are shown in Table 2.

3. Theoretical considerations

When the submarine pipeline is laid on the seabed without a gap and cover, currents and waves may cause local seabed scour below the pipeline. Fig. 3 is the sketch of the pipeline which is partially buried. A seepage flow underneath the pipe is generated due to the pressure difference between upstream (point B) and downstream (point A). This seepage flow increases with the increase of the current

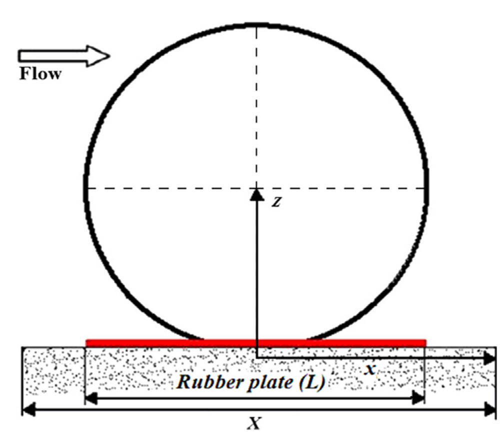

Fig. 2. Rubber plate underneath the pipeline on sandy bed.